Role of Stream Restoration on Improving Benthic Macroinvertebrates and In-Stream Water Quality in an Urban Watershed: Case Study

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Abstract: Many stream restoration projects do not include a requirement for long-term monitoring after the project has been completed, resulting in a lack of information about the success or failure of certain restoration techniques. The National Risk Management Research Laboratory, part of the U.S. EPA Office of Research and Development, evaluated the effectiveness of stream bank and channel restoration as a means of improving in-stream water quality and biological habitat in Accotink Creek, Fairfax City, Va., using discrete sampling and continuous monitoring techniques before and after restoration. This project monitored the effects of a 549 m (1,800 linear-ft) restoration of degraded stream channel in the North Fork of Accotink Creek. Restoration, which was intended to restore the stream channel to a stable condition, thereby reducing stream bank erosion and sediment loads in the stream, included installation of native plant materials along the stream and bioengineering structures to stabilize the stream channel and bank. Results of sampling and monitoring for 2 years after restoration indicated a slight improvement in biological quality for macroinvertebrate indices such as Virginia Stream Condition Index, Hilsenhoff Biotic Index, and Ephemeroptera, Plecoptera, Trichoptera taxa; the differences were statistically significant at 90% level of confidence with the power of greater than 0.8. However, indices were all below the impairment level, indicating poor water quality conditions. No statistically significant differences in chemical constituents and bacteriological indicator organisms were found before and after restoration as well as upstream and downstream of the restoration. The results indicated that stream restoration alone had little effect in improving the conditions of in-stream water quality and biological habitat, though it has lessened further degradation of stream banks in critical areas where the properties were at risk. Control of storm-water flows by placing best management practices in the watershed might reduce and delay discharge to the stream and may ultimately improve habitat and water quality conditions.

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Introduction

Since the inception of the Clean Water Act in 1972, the United States has made great efforts in restoring and preserving the physical, chemical, and biological integrity of the nation's waters. However, nearly one-half of the nation's assessed surface waters remain incapable of maintaining water quality adequate for supporting one or more designated uses, i.e., recreational swimming or drinking water supply (U.S. EPA 2007). One of the top causes of river and stream impairment is sediment or siltation. The National Water Quality Inventory 2000 Report (U.S. EPA 2002) estimated that about 30% of identified cases of water quality impairment are attributable to storm-water runoff. Over the last few decades, the U.S. EPA established several regulatory programs to address the various point and nonpoint sources (NPSs); however, less emphasis was placed on NPS pollution, which includes runoff from urban and agricultural areas.

Urbanization through land development alters watershed hydrology in several ways. The conversion of natural areas to impervious surfaces results in an increased volume of surface runoff because less water is able to infiltrate into the ground, i.e., more water enters the receiving water by surface runoff than via groundwater pathways. Examples of impervious surfaces in an urban area include roadway surfaces, parking lots, and rooftops. Surface runoff is also routed to the receiving stream via curbs, gutters, and pipes directed more quickly than water that

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percolates into the soil. Consequently, stream flows in urbanized watersheds increase in magnitude during wet weather flows as a function of directly connected impervious area (Schueler 1994).

Natural streams follow meandering patterns, which dissipates energy and minimizes scouring of the streambed and banks. Increased stream flows impact the natural stream channel morphology, which affects the physical, chemical, and biological integrity of the stream (Natural Resources Conservation Service 1998). Stream channels respond to increased stream flows by increasing their cross-sectional area through widening of the stream banks and down cutting of the stream bed. This, in turn, triggers a cycle of stream bank erosion and habitat degradation (Schueler 1994). Stream bank erosion can lead to bank instability and increased sediment loading downstream. This increased sediment load may cause water quality degradation, negatively impacting fish, benthic invertebrates, and other aquatic life in the stream. Channel instability and the loss of in-stream habitat structure, such as the loss of pool, run, and riffle sequences, also results from increased stream flows leading to degraded habitat for aquatic life. Klein (1979) noted that macroinvertebrate diversity drops sharply in urban streams in Maryland as a result of increased imperviousness.

In addition to the physical damage done to the streams, stormwater runoff may carry many types of pollutants which have the potential to significantly impact the biological community and change the mass of macroinvertebrate community. Normally, a healthy system will have a large variety of species while a stressed system will be represented by fewer species that are tolerant to the environmental stresses. For macroinvertebrate studies, this means that sensitive aquatic insect species, such as stoneflies, mayflies, and caddisflies are replaced by species, such as chironomids, tubificid worms, amphipods, and snails that are more tolerant of pollution and hydrologic stress. Macroinvertebrate index scores attempt to assess shifts in species and population dynamics. One way to mitigate these stream impacts is to conduct stream restoration. Stream restoration, used to stabilize stream banks and thus mitigate stream bank erosion, has been defined as "returning an ecosystem to a close approximation of its condition prior to disturbance" (Kondolf and Micheli 1995).

Even though the number of stream restoration projects has increased dramatically over the last decade, only about 10% of these projects have been monitored after the restoration and most of them only in a limited scope. Hence, the results of these substantial expenditures on these projects are unknown, especially in regard to improvement in water quality and biological habitat. The objective of this project was to investigate the effectiveness of stream restoration techniques on improving biological habitat and in-stream water quality in an impaired stream in an urban watershed. This objective was achieved by continuous monitoring of water quality and by collecting physical, chemical, and biological data in the receiving stream before and after stream restoration. Upstream control sites, which were rehabilitated earlier, were to provide an attainable goal for the current restoration work.

Sampling and Monitoring

Study Location

The Accotink Creek in Fairfax City, Va. was selected as the study location (Fig. 1). Accotink Creek and its tributaries within the City of Fairfax are important natural features that provide recreational and aesthetic values that enhance the quality of life in the city. The headwaters of Accotink Creek originate within the City of Fairfax and flow southeast through Fairfax County to its confluence with the Potomac River at Gunston Cove, which then flows into the Chesapeake Bay. As a tributary to the Potomac and Chesapeake Bays, Accotink Creek is subject to very strict water quality criteria. All state waters are designated for recreational uses and therefore must meet these water quality standards. The Accotink Creek headwater watershed has uncontrolled urban runoff that has resulted in the deepening and widening of the creek's channel, sediment removal from the stream reach and deposition downstream, and stream bank instability.

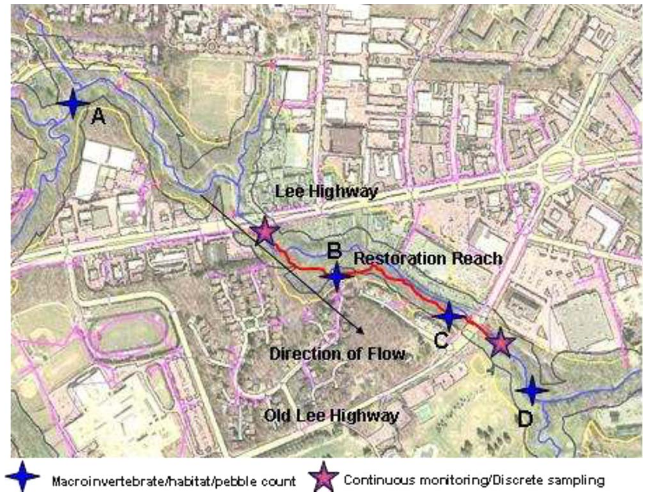

Fig. 1. Accotink Creek stream restoration project location

High runoff volume from impervious surfaces is the primary cause of stream degradation in the Accotink Creek watershed. Many of the fish and other aquatic life, which are important for the Creek's viability, began to disappear when the open areas were developed and paved (Fairfax 2005). Overall, the stream health, measured by the physical, biological, and habitat assessment, is fair to poor in the majority of the city; erosion potential remains at a very high level, sedimentation is a problem, and down-cutting streams threaten city utilities and surrounding property. The amount of storm-water runoff generated under existing conditions is almost twice the runoff that would be generated under 100% forested conditions (The Louis Berger Group 2005). The Fairfax County Stream Protection Strategy Baseline Study, conducted by the Department of Public Works and Environmental Services (DPWES), concluded that the benthic macroinvertebrate community health in the Accotink Creek was poor; habitat conditions were very poor; and fish taxa richness was low [Dept. of Public Works and Environmental Services (DPWES) 2001].

Accotink Creek was listed as impaired on Virginia's 1998, 303(d) Total Maximum Daily Load (TMDL) priority list due to violation of the State's water quality standard for fecal coliform (VADEQ 1998). As part of the TMDL study, the USGS Virginia District conducted ribotyping (deoxyribonucleic acid fingerprinting) on fecal coliform samples from Accotink Creek. The dominant bacterial sources were geese (24%), humans (20%), and dogs (13%). Other sources identified included ducks, cats, raccoons, sea gulls, cattle, and deer (USGS 2003).

Along with other best management practices (BMPs), the management plan called for stream bank restoration as an important method of improving stream conditions. Fairfax chose to focus on areas which stood to benefit the most from the use of BMPs and have attempted to coordinate improvements with their overall watershed strategy by using regional and holistic approaches where possible.

The Accotink watershed covers approximately $13.76\ km^2$ [1,376 ha (3,400 acre)] of drainage area within the Fairfax City limits. The majority of the soils are well drained and moderately coarse textured, with moderate infiltration rates; percent imperviousness is about 35% (DPWES 2001). Elevation in the City of Fairfax watershed ranges from 129.5 m (425 ft) above mean sea level (MSL) at its highest point to 86.9 m (285 ft) above MSL at the point Accotink Creek flows out of the city. The city is highly urbanized and characterized by commercial and high- and low-density residential development that accounts for greater than 60% of land uses with little space available for new development. There are few existing storm-water treatment practices (STPs) in the city that were installed prior to recent trends in storm-water regulations and limited space is available for adding large scale practices. Most of the city's current STPs are underground vaults which provide storage only and provide little, if any water quality treatment. Other existing practices include several dry ponds, which similar to the vaults; tend to provide limited water quality benefits.

Restoration of the stream channel was necessary to reduce loss of property, protect infrastructure, restore public safety, stop the destruction of downstream habitat, and restore aquatic life native to Fairfax. In the spring of 2002, the city completed stream restoration improvements on the North Fork of Accotink Creek from Stafford Drive to Lee Highway, upstream of the current monitoring project. The current project consisted of 549 m (1,800 ft) of stream restoration within the North Fork of Accotink from Lee Highway to Old Lee Highway in the City of Fairfax, Fairfax County, Va. (Fig. 1). The construction started on April 3, 2006 and was completed on June 6, 2006.

The stream restoration included placing bioengineering structures (coir fiber logs, erosion control fabrics, and live willow stakes) to prevent erosion and establish deeper rooted vegetation to stabilize the upper bank. Rock armoring was used to protect the lower stream banks in areas of higher energy to reduce stream bank erosion. Rock veins and step pools were constructed to reduce slope, slow water velocity, and protect stream banks by diverting stream flow from the edge of the channel toward the center of the stream forming the thalweg. Dense planting and seeding of native vegetation was done along the stream to protect exposed soils from erosion and sedimentation during heavy rainfall and high flows completed the channel restoration. These actions were intended to stabilize the stream channel to a more stable condition and reduce stream bank erosion, thereby reducing sediment loads in the stream. The use of rock was needed in this portion of the restoration due to encroachment of development into the floodplain. Previously restored upstream sections (e.g., Site A in Fig. 1) were able to incorporate more natural approaches and were able to reconnect the floodplain to the stream channel in some reaches, though step pools were also used. The current restoration attempted to retain many of the exiting trees in riparian zone, rather than clearing the floodplain and replanting. There were limited opportunities to provide habitat features on the east bank north of Old Lee Highway Bridge due to the proximity of a parking lot of the shopping center to the stream; much of the parking lot is in the 100-year flood plain.

Continuous Water Quality Monitoring

Standard water quality parameters (pH, conductivity, temperature, turbidity) were measured upstream and downstream of the restoration from December 2005 to March 2008 except during the period of construction. This water quality monitoring enabled the quantification of physical and chemical changes in the receiving water. Area-velocity flow meters combined with other monitoring probes (American Sigma, Loveland, Colo.) installed at two selected locations recorded average flow depth, velocity, water temperature, conductivity, and pH at 15 min intervals. Depth was measured using differential pressure (bubbler) or pressure transducer sensors. Twin 1 MHz piezoelectric crystals were used to measure Doppler-based velocity. Internal electronics combine the measured values using the stream cross section to compute an associated flow rate. In addition, a Yellow Springs Instruments (YSI) (Yellow Springs, Ohio) probe placed at the upstream border of the restoration reach was used to measure water temperature, specific conductivity, turbidity, dissolved oxygen, and pH also at 15-min intervals.

Discrete Water Quality Sampling

Both dry and storm event discrete samples were also collected at two locations above (Lee Highway) and below (Old Lee Highway) the restored area (Fig. 1) following standard U.S. EPA protocols from the middle of the water column in approximately the center of the stream flow. A storm event was defined as a minimum of 2.54 mm (0.1 in.) rainfall over a period of 6–24 h (Strecker et al. 2002). Dry weather conditions were defined as time that was proceeded by at least 72 h of no or only trace amounts of precipitation as per National Pollutant Discharge Elimination System protocol (U.S. EPA 1992). Wet weather samples were collected over a wide range of flow conditions, generally defined as at least 50% increase from baseflow conditions during or following a storm event. Single grab samples were collected in 2-L bottles by lowering the bottles from the bridge during significant wet weather events or by hand grab during dry weather or lesser wet weather events. Samples were either shipped by courier or brought back to the laboratory for analysis at the Urban Watershed Research Facility (UWRF) in Edison, N.J. Seven wet weather (two before restoration and five after restoration) and seven dry weather (two before restoration and five after restoration) sampling events were conducted with a full suite of analytes. Longer duration of prerestoration sampling was not possible as the city already had the project design, funding, and implementation plan in place, when this site was ultimately chosen for monitoring.

The samples were analyzed in triplicate for suspended solids (SS), chemical oxygen demand (COD), nutrients (total phosphate (TPO_4^{3-}), orthophosphate (OPO_4^{3-}), total nitrogen (TKN), ammonia (NH_3), nitrate (NO_3^-), and nitrite (NO_2^-)), and indicator organisms (fecal coliform, enterococci, and *E. coli*). The samples were analyzed following Standard Methods (American Public Health Association et al. 1998). Indicator organisms and macroinvertebrates, which are addressed next, are mutually exclusive indicators, and are not expected to affect each other.

Macroinvertebrate Sampling

Biological integrity above, within, and below the restoration area before and after restoration were evaluated using benthic macroinvertebrate data. Sampling locations are shown in Fig. 1. Sites A and restored upstream park (RUP) are upstream, previously restored, control sites; Sites B and C are within the current restored section; and Site D is a downstream, unrestored section. Sampling was conducted only during dry weather events to avoid potential organism drift during wet weather events. Benthic macroinvertebrates are a major component of healthy stream systems and are an important link in any aquatic food web, forming the core of the diet of many fish. Individual macroinvertebrate kick-net samples covering 2 m^2 of each riffle were collected using modifications of the established protocols of the U.S. EPA's *Rapid Bioassessment Protocol for Use in Wadeable Streams and Rivers* (Barbour et al. 1999), which the Virginia Department of Environmental Quality (VDEQ) employs for bioassessments. An area of 0.5 m $\times$ 0.5 m (0.25-m square) upstream of the net was sampled using the 0.5-m-wide kick net. A total of eight kick-net collections were composited into one sample for a total of 2 m^2 within each riffle during dry weather flow conditions. All organisms caught in the net were transferred to a sampling container. Samples were preserved with 70% ethanol before sending it to EPA Region 3's wheeling laboratory for analysis. There were three sampling events before the restoration (November, December, and March); five sampling events after restoration, three of which corresponded with the state sampling program (one in May, and two in September), with additional replicates (two) in November, corresponding to the first sampling event.

Macroinvertebrates retained on a No. 35 mesh dip net (500 μm) were randomly subsampled to 110 ± 20 organisms and identified using macroinvertebrate identification keys of Merritt and Cummins (1996), Pennak (1989), Peckarsky et al. (1990), and Thorp and Covich (1991). After identification and enumeration of macroinvertebrates, the Virginia Stream Condition Index (VASCI), total taxa, total taxa family, Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa, EPT family, Hilsenhoff Biotic Index (HBI), percent of scrapers, and percent of most dominant taxon were calculated.

HBI (Hilsenhoff 1987), originally developed to assess low dissolved oxygen caused by organic loading, is also considered to be sensitive to the effects of impoundment, thermal pollution, and some types of chemical pollution such as nutrient enrichment and high sediment loads (Hilsenhoff 1998; Hooper 1993). HBI was later modified to accommodate comparisons of samples collected throughout the year. There was no defined impairment threshold value. Samples with HBI values of 0–2 are considered clean, 2–4 are slightly enriched, 4–7 are enriched, and 7–10 are polluted (Hilsenhoff 1988).

The VASCI is a multimetric biological index developed using recent advances in bioassessment methods and is calibrated from Virginia data for use in the assessment of Virginia's nontidal, upland streams. This index was used to compare with regional and local reference data sets. The VASCI ranges from 0–100 (100 is the best possible), with 60 being the impairment threshold in Virginia. VASCI and HBI are inversely related with respect to water quality. EPT family richness is also commonly used to assess water and habitat quality and is defined as <2=poor water quality; $2-5$=fair; $6-10$=good; and >10=excellent quality.

Physical Habitat Monitoring

Stream channel cross-sectional measurements were taken using a folding ruler and a flexible tape measure stretched perpendicular to the direction of stream flow. Measurements were taken from bank to bank at 0.15 m (0.5 ft) increments close to the banks and at 0.3–0.6 m (1–2 ft) interval elsewhere at four different locations [one upstream (Site A), one downstream (Site D), and two in restored area (Sites B and C)] once before restoration and once after restoration.

The USGS conducted pebble counts to document the surface particle size distribution of coarse riverbed material at the same five locations as the macroinvertebrate samples. Pebble counts were conducted twice before restoration and once after restoration. Counts were performed in a manner similar to that described by Wolman (1954); minor modifications to the methods were needed to accommodate site characteristics. Because Accotink Creek is a relatively narrow stream, an entire stream riffle with multiple transects were needed for the pebble count to be more representative, rather than just an individual transect within a riffle. On average, the sampled riffles were about 7.62 m (25 ft) long and approximately 5.49 m (18 ft) wide. Pebbles were selected for size determination from within the wetted perimeter of the stream, and were chosen for size determination using the first-blind-touch approach. Particle size was determined using a pebble count template (which provided a standard classification system). Particles that were smaller than 2 mm were compared to a sand gauge card to determine size. A total of 100 pebbles were selected from within each riffle section. By classifying particles using the template and sand card, the particles could be grouped into sieve size classes according to the Wentworth scale. Following size classification, the data were plotted to summarize the relative size classes identified in each riffle.

In addition, a rapid bioassessment was performed once after the restoration according to EPA protocols (Barbour et al. 1999) using the physical characterization/water quality and habitat assessment (high gradient streams) field data sheets, to asses and document current conditions.

Results and Discussion

Continuous Water Quality Monitoring

Daily averages of the continuous monitoring 15-min data collected for pH, conductivity, turbidity, temperature, and depth recorded by YSI are shown in Figs. 2 and 3. The gap in the data from June 2006 to August 2006 was due to the equipment being damaged after a large storm event, which came right after the restoration was completed. Three inches of rainfall fell in 2 h on June 9th. During the period of June 23–26, 2006, there was major flooding in the area. On June 25, 2006, in Fairfax County, Va., two stream flow gauges recorded peaks near the 50-year recurrence interval and one stream flow gauge recorded a peak near the 100-year recurrence interval.

As expected, pH stayed close to neutral ranging between 6.5 and 8. Temperature changed seasonally. Turbidity and conductivity appear to be event-related with spikes coming during wet weather events. The conductivity also was seasonally dependent, since it peaked during winter, likely due to runoff from salt during snow melt. Salting is a regular snow and ice roadway management practice in the City of Fairfax.

Discrete Water Quality Sampling

Results of the discrete samples collected before and after restoration in both upstream (Lee Highway) and downstream (Old Lee Highway) locations and analyzed for physical and chemical constituents are shown in Table 1. Seven wet weather (one before, one during, and five after restoration) and seven dry weather (one

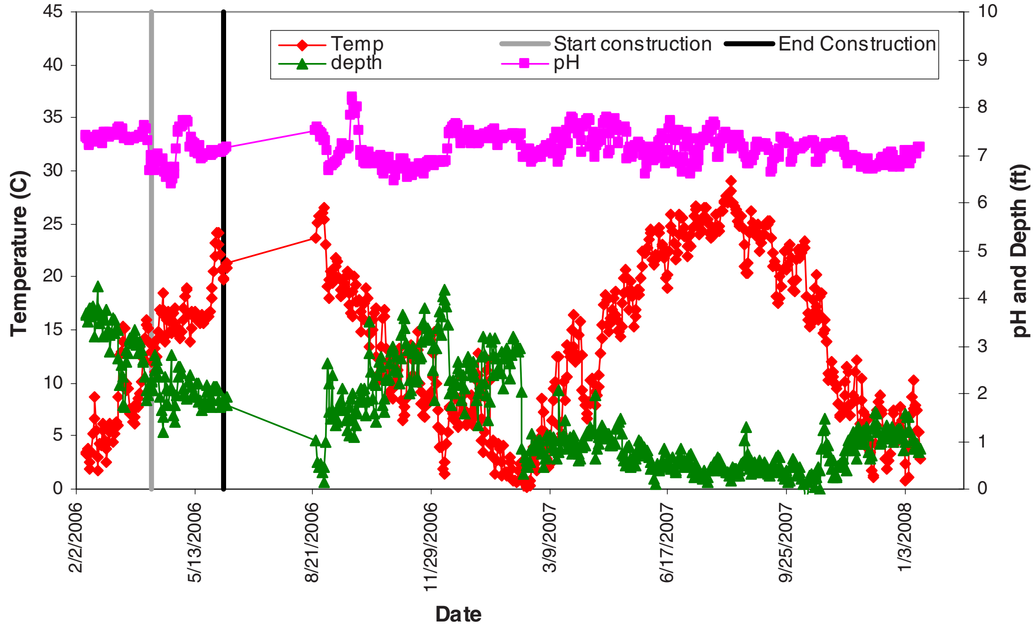

Fig. 2. Example of continuous water quality monitoring for temperature, pH, and depth

before, one during, and five after restoration) sampling events were conducted with a full suite of analytes. Data in Table 1 indicate that wet weather concentrations of TPO_4^{3-}, NH_3, TKN, SS, and COD were typically higher than the dry weather concentrations. SS concentrations ranged between 0.20–20 mg/L and 89–291 mg/L, respectively, for dry and wet weather samples. COD concentrations ranged between 0.4–15 mg/L and 11–73 mg/L for dry and wet weather samples, respectively.

Concentrations of wet weather SS increased significantly after restoration. This may be because restoration work disturbed the stream channel and liberated sediments. Also, it takes time to stabilize the stream banks as plants require time to grow before being effective. Concentrations of SS ranged between 3–13 mg/L and 97–291 mg/L for before and after restoration, respectively, at the downstream location. Concentrations of COD did not change and ranged between 12–73 mg/L. TPO_4^{3-}, NH_3, and TKN concentrations increased slightly after restoration. Concentrations ranged between 0.07–0.35 mg/L, 0.5–1.3 mg/L, and <0.01–0.29 mg/L for TPO_4^{3-}, TKN, and NH_3, respectively, after restoration. However, these changes are not great enough to associate with restoration activities. The one-way ANOVA statistical analysis indicates that there is no statistically significant difference ($P > 0.05$ at $\alpha = 0.05$) between before and after restoration and as well as upstream and downstream of the restoration except for wet weather SS ($P = 0.005$ for upstream and $P = 0.029$ for downstream at $\alpha = 0.05$) as one would expect as the source of pollution in the watershed is not addressed. This may be due to resuspen-

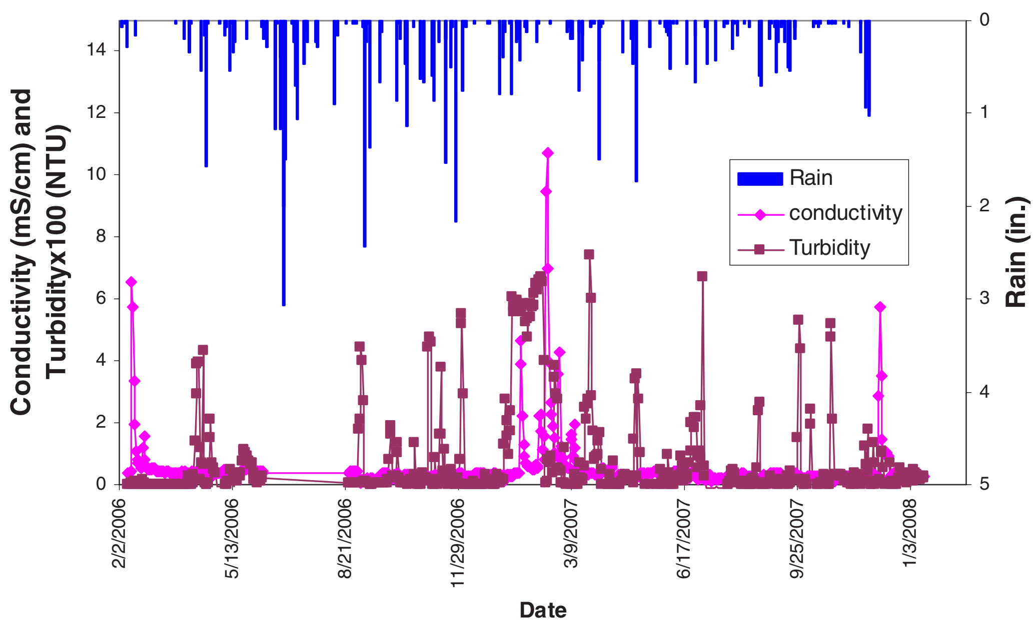

Fig. 3. Example of continuous water quality monitoring for conductivity and turbidity

Table 1. Results of Water Quality Analysis (Physical and Chemical Constituents)

	Date	Flow condition	Upstream (Lee Highway) SS	COD	TPO_4^{3-}	TKN	NH_3	Downstream (Old Lee Highway) SS	COD	TPO_4^{3-}	TKN	NH_3
Prerestoration	March 1, 2006	Dry	0.67	0.37 (0.44)	0.03 (<0.01)	0.07 (<0.01)	0.03 (<0.01)	2.00	1.88 (0.34)	0.02 (<0.01)	0.09 (0.01)	0.03 (<0.01)
	April 5, 2006	Wet	6.67	14.92 (0.39)	0.02 (<0.01)	0.40 (0.02)	0.08 (<0.01)	3.33	19.44 (2.31)	0.03 (<0.01)	0.39 (0.02)	0.11 (<0.01)
During restoration	May 2, 2006	Dry	1.40	7.61 (0.34)	0.04 (0.06)	0.20 (0.02)	0.01 (<0.01)	25.07 (1.04)	10.33 (1.11)	0.04 (<0.01)	0.54 (0.05)	0.10 (<0.01)
	May 9, 2006	Wet	26.67	61.66 (0.88)	0.35 (0.04)	0.58 (0.04)	0.19 (<0.01)	13.25 (0.35)	68.01 (2.04)	0.13 (<0.01)	0.44 (0.02)	0.07 (0.01)
Postrestoration	June 20, 2006	Wet	4.40 (0.28)	28.86 (1.21)	0.06 (<0.01)	0.61 (0.01)	0.06 (<0.01)	6.30	22.25 (0.88)	0.07 (0.01)	0.65 (0.01)	0.06 (<0.01)
	September 21, 2006	Dry	0.40	15.24 (0.92)	0.06 (<0.01)	0.32 (0.03)	0.08 (<0.01)	0.22	28.45 (0.35)	<0.01 (<0.01)	0.37 (0.01)	0.03 (0.01)
	October 13, 2006	Wet	89.10 (1.84)	11.08 (0.67)	0.28 (<0.01)	0.49 (0.02)	<0.01 (<0.01)	96.80	12.48 (0.85)	0.32 (0.01)	0.50 (0.03)	0.01 (<0.01)
	November 16, 2006	Wet	252.10 (10.04)	72.52 (0.94)	0.24 (<0.01)	0.83 (0.04)	<0.01 (<0.01)	290.60	67.08 (2.31)	0.22 (<0.01)	0.95 (0.05)	<0.01 (<0.01)
	December 14, 2006	Dry	0.20	7.69 (1.27)	0.04 (<0.01)	0.18 (0.01)	<0.01 (<0.01)	1.20	6.03 (0.57)	0.04 (0.01)	0.21 (0.02)	0.01 (0.02)
	April 4, 2007	Dry	30.32	30.11 (1.21)	0.03 (0.02)	1.35 (0.02)	0.73 (<0.01)	19.60 (2.26)	20.35 (2.42)	0.04 (0.02)	1.28 (0.01)	0.76 (0.02)
	April 15, 2007	Wet	127.50	21.96 (1.60)	0.13 (0.01)	0.99 (0.07)	0.29 (<0.01)	120.20 (0.85)	27.03 (1.40)	0.12 (0.01)	0.63 (0.02)	0.29 (0.01)
	July 11, 2007	Wet	171.30 (0.99)	23.27 (2.38)	0.29 (0.06)	1.35 (0.05)	0.14 (<0.01)	204.40	29.24 (1.02)	0.35 (0.02)	1.30 (0.07)	0.14 (0.01)
	September 18, 2007	Dry	2.40 (1.41)	3.36 (1.08)	0.04 (<0.01)	1.14 (0.06)	ND	ND	3.81 (1.21)	0.03 (<0.01)	0.51 (0.07)	ND
	January 16, 2008	Dry	0.30 (0.14)	1.05 (1.14)	0.03 (<0.01)	0.64 (0.02)	0.03 (<0.01)	ND	1.81 (0.56)	0.02 (0.02)	0.49 (0.04)	0.04 (<0.01)

Note: Concentrations in mg/L. Restoration was completed on June 6, 2006. Brackets indicate standard deviation.

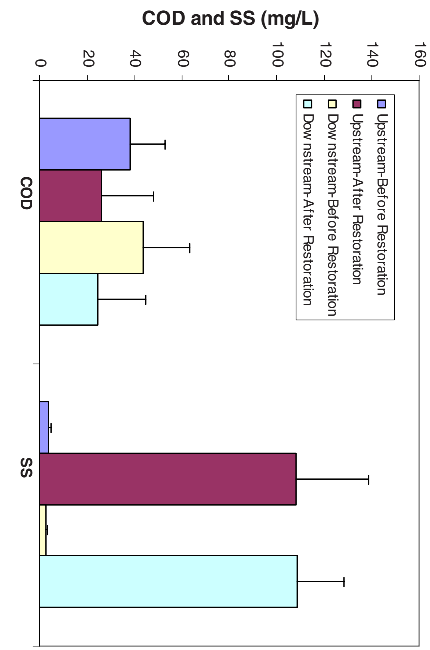

Fig. 4. Average of wet weather concentrations of COD and SS before and after restoration (error bars are standard deviation)

sion of solids during wet weather flows. However, these concentrations are well below Virginia Water Quality Standards (State Water Control Board 2007) and the concentrations may not be great enough to have significant effect on macroinvertebrates populations. Concentrations of SS, COD, TPO_4^{3-}, NH_3, and TKN in wet weather samples before and after restoration in both upstream and downstream locations are shown in Figs. 4 and 5.

Results of the discrete samples collected before and after restoration in both upstream (Lee Highway) and downstream (Old Lee Highway) locations and analyzed for bacteriological constituents are shown in Table 2. Data in Table 2 indicate that wet weather concentrations of fecal coliform, enterococci, and *E. coli* are much larger than the dry weather conditions. Except for the November 6, 2006 wet weather sampling event, both upstream and downstream samples had concentrations in the same order of magnitude. Concentrations of all three indicator organisms in the November 6, 2006 samples were much higher in the downstream samples compared to upstream samples. The November 2006 sampling event may be anomalous. Concentrations of organisms vary with seasons, as expected, and summer concentrations were significantly higher compared to other seasons as reported by Selvakumar and Borst (2006). The one-way ANOVA statistical analysis indicates that there is no statistically significant difference between before and after restoration as well as upstream and downstream of the restoration. Concentrations of fecal coliform, enterococci, and *E. coli* in wet weather samples before and after restoration in both upstream and downstream locations are shown in Fig. 6.

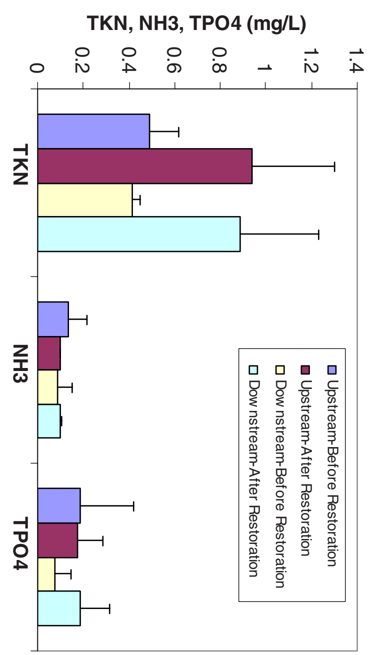

Fig. 5. Average of wet weather concentrations of TKN, NH_3, and TPO_4^{3-} before and after restoration (error bars are standard deviation)

Table 2. Results of Water Quality Analysis (Indicator Organisms)

	Date	Flow condition	Upstream (Lee Highway) Fecal coliform	Upstream (Lee Highway) Enterococci	Upstream (Lee Highway) *E. coli*	Downstream (Old Lee Highway) Fecal coliform	Downstream (Old Lee Highway) Enterococci	Downstream (Old Lee Highway) *E. coli*
			Concentrations in CFU/100 mL					
Prerestoration	March 1, 2006	Dry	31 ± 9	7 ± 3	23 ± 7	74 ± 46	20 ± 10	31 ± 12
	April 5, 2006	Wet	$1,867 \pm 719$	119 ± 39	365 ± 55	1865 ± 212	214 ± 94	520 ± 204
During restoration	May 2, 2006	Dry	160 ± 36	66 ± 26	101 ± 30	224 ± 85	338 ± 84	179 ± 42
	May 9, 2006	Wet	$77,000 \pm 6,557$	$4,900 \pm 608$	$7,733 \pm 252$	$74,333 \pm 6,028$	$7,100 \pm 361$	$3,533 \pm 551$
Postrestoration	June 20, 2006	Wet	$33,667 \pm 6,807$	$1,163 \pm 162$	$8,700 \pm 1,082$	$26,667 \pm 5,033$	$1,665 \pm 398$	$11,167 \pm 2,021$
	September 21, 2006	Dry	643 ± 133	70 ± 13	436 ± 76	285 ± 157	78 ± 1	302 ± 12
	October 13, 2006	Wet	$3,887 \pm 271$	$3,933 \pm 457$	$11,267 \pm 1,106$	$7,033 \pm 252$	$6,333 \pm 551$	$13,667 \pm 666$
	November 16, 2006	Wet	777 ± 25	$3,453 \pm 334$	30 ± 26	$143,500 \pm 12,021$	$6,600 \pm 600$	$99,000 \pm 8,485$
	April 4, 2007	Wet	$5,117 \pm 776$	$6,183 \pm 2,646$	$3,900 \pm 1,905$	$4,567 \pm 208$	$2,883 \pm 1,089$	$2,600 \pm 385$
	April 15, 2007	Wet	$5,033 \pm 513$	ND	$2,300 \pm 361$	$6,167 \pm 351$	ND	$2,700 \pm 458$
	July 11, 2007	Wet	$67,500 \pm 4,950$	148 ± 53	$18,000 \pm 4,000$	$52,333 \pm 10,693$	163 ± 90	$9,267 \pm 513$
	September 18, 2007	Dry	$1,000 \pm 586$	15 ± 5	104 ± 23	233 ± 48	19 ± 8	93 ± 11
	January 16, 2008	Dry	72 ± 71	ND	200 ± 141	37 ± 28	ND	250 ± 71

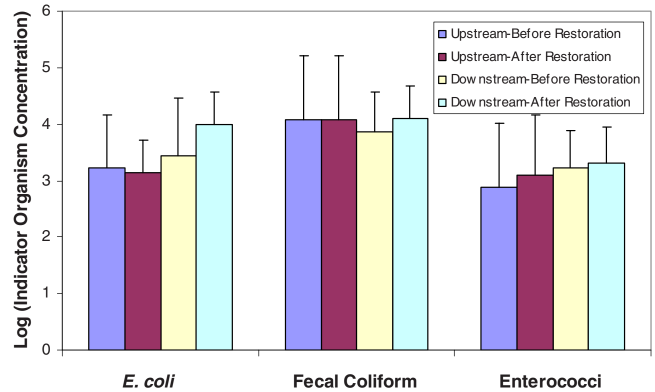

Fig. 6. Summary of indicator organism concentrations before and after restoration (error bars are standard deviation)

Macroinvertebrate Sampling

The results for VASCI and HBI indices, number of EPT taxa families, and number of total taxa families for all sampling events are summarized in Table 3. Total number of taxa families between sampling locations ranged between 3 and 10 and typically had more than five families represented. EPT taxa at the family level ranged between 0 and 3 between sampling locations and typically are 1 and 2 indicating poor water and habitat quality. All of the sites, including the control sites, which were previously restored reaches along the Accotink Creek, received VASCI scores less than 60, the impairment threshold in Virginia, indicating impaired macroinvertebrate conditions. The scores of the HBI index for all the sites are within the "enriched" category (4–7) as defined by Hilsenhoff (1988) which indicates that most species identified are moderately tolerant of polluted water with high organic content or excessive nutrient concentrations.

Table 3 summarizes the average values for the parameters before and after restoration. Benthic invertebrate data collected to date indicate areas within the restoration reach have VASCI scores that are not significantly different than before the restoration. Control sites, which were previously restored reaches along the Accotink Creek, show substantial variability before and after restoration. The VASCI score at control site A was much smaller than expected in the pre-restoration sampling event. This may be due to seasonal variability and related to the velocities experienced in this stream that remain unchanged with this management strategy. Upstream control site VASCI scores following restoration were intended to provide an attainable goal for Sites B and C within the current restoration reach. Both sites B and C in the restored section were moved slightly owing to the fact that the restoration altered the riffle locations and the original riffle no longer existed in the exact, same location though any movement was representative of the same reach. The HBI average was 6 in the restored area and downstream sites and 5.9 in upstream sites after restoration. All were ranked as enriched per Hilsenhoff (1988), and there were no significant difference between indices.

Macroinvertebrate data completed for VASCI, HBI, and EPT taxa families showed a slight improvement in conditions between pre- and postrestoration for all sites up to 2 years after the restoration (Table 4). A *t*-test indicated a statistically significant change in VASCI ($P=0.014$) and HBI indices ($P=0.012$) and total number of EPT Taxa families ($P=0.017$) between before and after restoration at $\alpha=0.1$ with the power of greater than 0.8 (0.876, 0.894, and 0.838 respectively for VASCI, HBI, and EPT taxa) as the change occurred was greater than that would be expected by

Table 3. Results of Macroinvertebrate Analysis

	Date	Species	Site A (~120 m north of Lee Hwy) upstream	Site B (~100 m south of Lee Hwy) restoration area	Site C (~10 m north of Old Lee Hwy) restoration area	Site D (~200 m south of Old Lee Hwy) downstream	Site RUP (~50 m west of bridge at River Road) upstream
Prerestoration	November, 3–4, 2005	VASCI	***21.2***	29.1	24.3	25.9	
		HBI	***6.86***	**5.87**	5.94	6.06	
		# of EPT taxa families	1	2	1	1	
		# of total taxa families	5	6	5	5	
	December, 7–8, 2005	VA SCI	21.5	25.1	30.7	25.6	28.5
		HBI	5.91	6.17	6.03	6.13	5.95
		# of EPT taxa families	1	1	1	1	1
		# of total taxa families	5	5	9	6	6
	March 13–14, 2006	VASCI	25.2	23.9	26.3	27.2	***24.2***
		HBI	6.03	***6.82***	6.03	6.59	6.13
		# of EPT taxa families	2	1	1	1	1
		# of total taxa families	5	5	6	6	8
Postrestoration	September 21, 2006	VASCI	**36.8**	28.2	**33.5**	**32.2**	**38.6**
		HBI	6.02	5.9	**5.75**	**5.71**	**5.28**
		# of EPT taxa families	3	2	2	2	3
		# of total taxa families	5	4	7	6	4
	November 15, 2006	VASCI	29.6	26.6	28.4	24.8	33.3
		HBI	**5.35**	6.09	6.03	5.98	5.79
		# of EPT taxa families	2	1	2	1	2
		# of total taxa families	6	5	7	5	10
	May 9, 2007	VASCI	27.9	***22.8***	***12.3***	***22.2***	26
		HBI	6.09	6.59	6.02	***6.79***	6.08
		# of EPT taxa families	3	1	0	2	2
		# of total taxa families	7	5	3	5	6
	September 18–19, 2007	VASCI	32	**30.5**	22.5	31.7	32.2
		HBI	5.9	5.93	6	5.86	5.84
		# of EPT taxa families	3	2	2	2	2
		# of total taxa families	6	7	8	7	7
	November 14–15, 2007	VASCI	27.1	28.5	30.4	29.2	28.8
		HBI	6.47	6.02	***6.13***	5.97	***6.16***
		# of EPT taxa families	1	1	1	1	1
		# of total taxa families	6	7	8	6	9

Note: Bold indicates maximum score, while italic bold indicates minimum scores (only VASCI and HBI assessed).

Table 4. Average Macroinvertebrate Indices and EPT Taxa Families before and after Restoration

	Site RUP[a]		Site A		Site B		Site C		Site D	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
VASCI	26.4 (3.0)	31.8 (4.8)	22.6 (2.2)	30.7 (3.9)	26.0 (2.7)	27.3 (2.9)	27.1 (3.3)	28.7 (4.6)	26.2 (0.9)	28.0 (4.4)
HBI	6.04 (0.13)	5.83 (0.35)	6.27 (0.52)	5.96 (0.41)	6.29 (0.49)	6.11 (0.28)	6.17 (0.32)	5.99 (0.14)	6.26 (0.29)	6.06 (0.42)
EPT taxa families	1.00 (0.0)	2.00 (0.71)	1.33 (0.58)	2.40 (0.89)	1.33 (0.58)	1.40 (0.55)	1.00 (0.0)	1.40 (0.89)	1.00 (0.0)	1.60 (0.55)
	Upstream controls				Restoration reach				Downstream affects	

Note: Parentheses indicate standard deviation.

[a]RUP=Restored upstream park.

chance. The results for VASCI and HBI indices are shown in Figs. 7 and 8, respectively. Macroinvertebrate population can be impacted by the time of the year the samples were collected. Comparison of data within a season was only possible for the fall season. The fall season data were collected in 2005 (two events) before restoration and 2006 (two events), and 2007 (two events), which were collected after the restoration. A t-test indicated that there is no statistically significant differences for both VASCI and HBI indices ($P > 0.05$).

An important factor influencing the slow recovery of benthic invertebrates in this system may be the continued impact of uncontrolled wet weather flows. The stream restoration likely created more habitats through the added pool-riffle structure incorporated in the restoration, but little or no volume control management was done in the watershed to attenuate wet weather flow volumes during this phase of watershed enhancement. Volume control to reduce flow velocities (e.g., stream bed scouring) from directly connected impervious areas and continuation of invertebrate collection sensitive to timing may improve recorded macroinvertebrate conditions in the restored reach. Moreover, macroinvertebrate communities may be limited by water quality since many of the taxa collected were considered tolerant of adverse chemical conditions.

There was also no significant difference in the total number of macroinvertebrates between the upstream, downstream, and restored sites. The upstream, downstream, and restored areas have similar percent dominance of taxa, and the most dominant taxa at these sites were Chironomidae, Hydropsychidae, Naididae, and Lumbriculidae, representing 87% of the upstream site samples, 93% of the restored area samples, and 92% of the downstream samples composed of these four families. All other families were relatively rare, most composing less than 1% of represented taxa (i.e., 1–2 taxa).

While there were no differences in the total number of families, there were more Chironomidae than Hydropsychidae at all sites before restoration. This was reversed after the restoration as there were more Hydropsychidae than Chironomidae except for one sampling event. It is plausible that restoration created more stable substrates which are required for attachment by net-spinning Hydropsychids. Many Chironomidae are silt and sand tolerant and early colonizers follow streambed scouring implying that the system is still coming to equilibrium.

Overall, the poor VASCI scores and relatively high HBI indicate that water quality or hydraulic changes may be limiting macroinvertebrate recovery following restoration activities. The dominant taxa found in Accotink Creek (pre- and postrestoration) suggest a variety of pollutants (e.g., nutrients, metals, other trace toxicants) could be responsible for structuring the observed communities. Also, macroinvertebrates often become dislodged from their substrate during high stream flows that occur after rain events, and then drift to downstream habitats (Borchardt 1993). Moreover, additional monitoring is needed to detect changes in macroinvertebrate communities over time. Improvement may require more than 2 years postrestoration, a finding common to many stream restoration projects (Gregory Pond, personal communication, U.S. EPA Region 3 Wheeling Laboratory, 2008); however, upstream Sites A and RUP were monitored 3–5 years since these areas were restored and scores still indicate impairment.

There are a number of potential limiting factors that have ef-

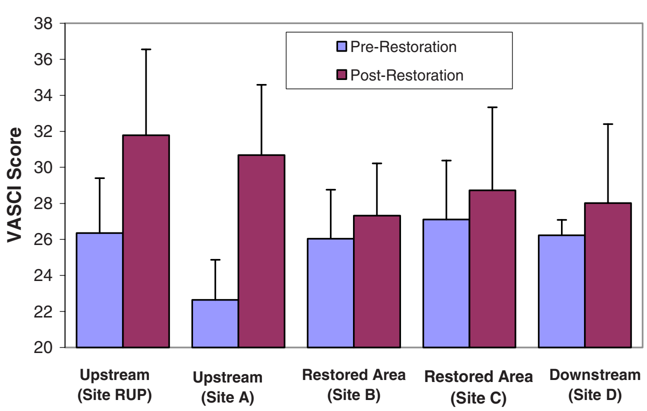

Fig. 7. VASCI scores for before and after the Accotink Creek stream restoration (error bars are standard deviation)

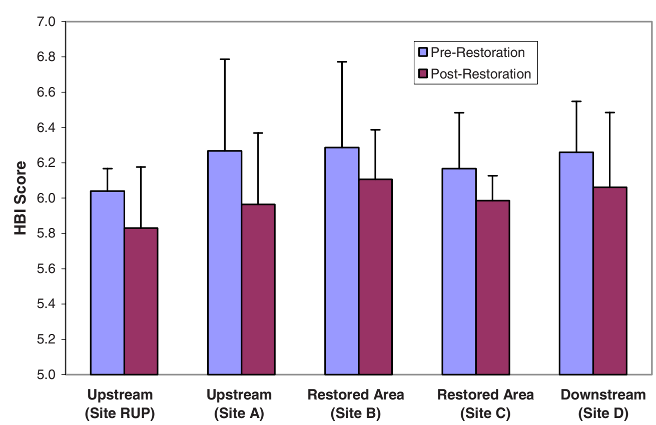

Fig. 8. HBI scores for before and after the Accotink Creek stream restoration (error bars are standard deviation)

fects on macroinvertebrates: Organic pollutants associated with dry weather flow generally reduces invertebrate diversity dramatically, resulting in pollutant tolerant species such as Chironomidae. Wet weather flows may move the bed sediments frequently while introducing the majority of pollutants. Increased turbidity has been associated higher drift densities of invertebrates. Also, riparian deforestation associated with urbanization reduces food availability, affects stream temperature, and disrupts sediment, nutrient, and toxin uptake from surface runoff. Horner et al. (1997) reported that macroinvertebrate indices decreased with increasing imperviousness in Puget Sound, Wash. tributaries.

The current assessment has shown marginal statistically valid results in the improvement of water quality indices for macroinvertebrates, though values are still indicating impairment. The current statistics on the VASCI scores of all restored sites (Sites A, B, C, and RUP) is 28.8 with a standard deviation of 5.6. It would require a minimum of 17 samples to potentially measure a five point increase in the score (e.g., 34) assuming a standard deviation of 5 at a power of 0.8. Based on the assumption that the current restoration work has actually improved scores and that additional macroinvertebrate recovery will continue to take place, it will take next 2.5 years to accumulate this many samples. However, there is no conclusive evidence that score will continue to improve. Including Site D, the unrestored reach, the peak scores of the VASCI (4 out of 5) and HBI (3 out of 5) came on the first event measured after the restoration in September 21, 2006 while the minimum VASCI scores came two events later in May 9, 2007 (3 out of 5) as noted in Table 3. Spring sampling may have been impacted by winter road salting (see Fig. 3 for conductivity values), though this effect, if real, appears to be temporary as the scores bounce back in September 2007. Inherent in this sampling program is year to year climate variability, and changing instream conditions, so assumptions of monotonically increasing scores may not be valid. However, if additional, substantial BMP control measures were implemented in the watershed to control storm discharges to the stream; additional sampling might discern rapid changes in the scores.

The stream restoration has theoretically protected the stream from further degradation due to larger storms; however, smaller storms are still released to the stream without any control. Most rainfall events are much smaller than design storms used for urban drainage models or stream restoration design. In any given area, most frequently recurrent rainfall events are small (less than 1 in. of daily rainfall). For example, 90% of the annual rainfall comes in storms smaller than 0.9 in/day in Cincinnati (Roesner et al. 1991). For small rains, impervious areas contribute most of the runoff flows and pollutants (R. Pitt, "Small storm hydrology," University of Alabama-Birmingham, unpublished manuscript, presented at Design of Stormwater Quality Management Practices, Madison, Wis., May 17–19, 1994). The capture and treatment of these small storms would lead to improved water quality since the total pollutant load and increased flow velocities to the receiving streams would be minimized. Storm-water BMPs could be targeted at controlling a greater portion of the annual runoff volume; this has been termed small storm hydrology (R. Pitt, "Small storm hydrology," University of Alabama-Birmingham, unpublished manuscript, presented at Design of Stormwater Quality Management Practices, Madison, Wis., May 17–19, 1994) and a simple knee of the curve analysis can be used to identify the break point between storm return period and control of annual volume (Heaney et al. 1977).

If such a BMP plan were implemented, due to the tight grouping in the standard of deviation of the indices, a 50% increase in VASCI scores would theoretically only require six additional samples at a power of 0.8 to observe statistically valid results. Scores indicating an increase to unimpaired score, e.g., a score of 60 for VASCI or 100% increase in scores, would theoretically only require an additional seven samples to obtain 0.90 power results assuming a standard deviation of 15. Potentially, one year after additional and substantial BMP controls were put in place targeting the knee of the curve control volume, e.g., 90% of annual rainfall volume, a sampling program might be able indicate significant improvement. Therefore, identifying the number and placement of BMPs to address this substantial control in the watershed remains to be defined; implementation of one or two BMPs would most likely be insufficient to measure any effect given the currents scores and year to year variability.

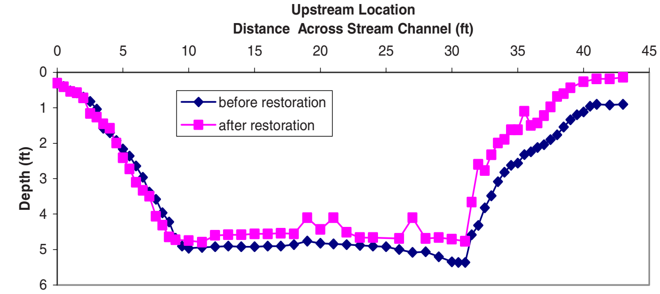

Fig. 9. Representative depth profiles before and after restoration at an upstream location from west to east (Site A)

Physical Habitat Monitoring

Figs. 9 and 10 show the channel profiles at two different locations. In the upstream location, the bottom contours did not change much after restoration. In the restored area, depth profile showed a deeper and more sharply defined bottom contour after restoration compared to before restoration. Bottom depth changed from approximately 2.13 m (7 ft) to 3.35 m (11 ft). Substrate was mostly gravel and cobble comprising 90–95% of the streambed of the creek in the restored area, whereas gravel and cobble comprised of 77–84% of the streambed upstream of the restoration.

The pebble count data are summarized in Table 5 and Fig. 11 (within restoration), and these data indicate that, to date, very little has changed in this stream reach. By evaluating the pebble count data at each site over time, there seems to be a slight increase in size in the postrestoration (October 2006) sampling at both the most upstream and downstream cross sections. However, as the most upstream site is a control that is above the restoration, it cannot be concluded that the slight increase in particle size at

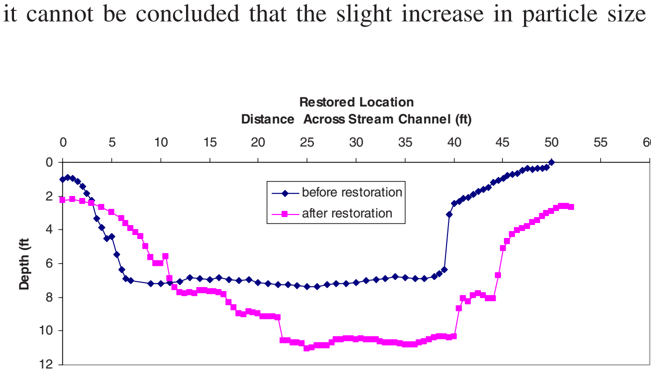

Fig. 10. Representative depth profiles before and after restoration at a restored location from west to east (Site B)

Table 5. Results of Pebble Counts

Date	Pebble count data	Site A—above Lee Hwy (above restoration)	Site B—below Lee Hwy (within restoration)	Site C–above Old Lee Hwy (within restoration)	Site D–below Old Lee Hwy (below restoration)	Site 5—Ranger Road (above restoration)
November 3, 2005	% silt/clay	3	0	0	2	
prerestoration	% sand	13	11	9	4	
	% gravel	84	76	61	90	
	% cobble	0	13	30	4	
	Particle size (mm)	7.9 ± 3.9	19.1 ± 3	34.0 ± 2.5	19.9 ± 2.0	
March 1, 2006	% silt/clay	3	0	0	2	2
prerestoration	% sand	20	5	9	33	14
	% gravel	76	87	60	65	68
	% cobble	1	8	31	0	16
	Particle size (mm)	6.3 ± 4.5	20.5 ± 2.6	29.5 ± 3	4.3 ± 8	8.2 ± 6.1
October 3, 2006	% silt/clay	1	0	0	4	0
postrestoration	% sand	17	5	2	4	21
	% gravel	79	82	77	76	73
	% cobble	3	13	18	16	6
	Particle size (mm)	8 ± 4.5	24.2 ± 2.4	32.2 ± 2.4	29.2 ± 2.2	24.8 ± 2.8

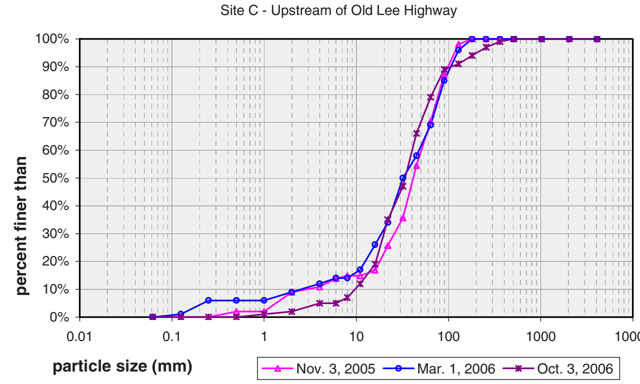

Fig. 11. Example of pebble count results

the most downstream site is caused by the restoration. The other three intermediate sites demonstrate few changes in the size distributions over time. This lack of change in the stream bed size classes is most likely due to the restoration not changing the rate of water courses down the stream and also supports the need for additional controls (BMPs) in the watershed to control volume.

The Rapid Bioassessment, performed in 2008 after the restoration according to EPA protocols (Barbour et al. 1999), indicated that physical characterization of the riparian vegetation was dominated by trees mostly hardwoods, in the recently restored reach, with exception of the area just upstream of Old Lee Highway, which corresponding to sampling Site C. This area and the run up next to the parking lot were described as partly open, while other sections were partly shaded. The previously restored upstream reach had one third described as grasses with remainder described as shrubs with these reaches described as partly open. The habitat assessment scores for riparian vegetative zone width ranged in condition category from poor to optimal, with the highest rating in one of the upstream previously restored reaches; two poorer riparian zones reaches were just above the Old Lee Highway Bridge but also by RUP which was a park. Vegetative protection scores were mostly suboptimal to optimal, with lowest readings of marginal upstream of the Old Lee Highway and behind the parking lot (due to the limited strip for vegetation on the right bank). The area just above the Old Lee Highway underwent the most reconstruction, in part to protect the bridge.

Conclusions

Stream restoration was successful in stabilizing stream banks, preventing bank sloughing, and further incision. This was important to the infrastructure in the stream restoration area and property owners of Fairfax City. If one of the goals of stream restoration is to restore habitat and biological communities, stabilizing banks alone is not enough to bring back species that depend on good water quality. Reduction of storm-water runoff volumes and associated pollutants of concern must be addressed through pollution source control and storm-water retrofits to achieve improved biological outcomes. Our results confirm with the suspicion many people have had regarding stream restoration. Beechie et al. (1996) pointed out that traditional approaches to aquatic habitat restoration concentrating on repairing or enhancing specific habitat conditions rather than restoring the landscape processes that form and sustain high quality aquatic habitats is not effective. Laeser and Stanley (2004) concluded that local restoration in and around streams are insufficient for improving the water quality of the stream as there were no changes in nutrient concentrations in association with restoration activities. Many habitats are a result of change; attempts to fix them at a particular point in space or time fail to recognize that stream channels are dynamic and that high quality habitats are a product of this dynamism. Unless larger scale watershed issues are addressed in restoration planning, the current practice of direct structural modification of channels at the site level is unlikely to reverse aquatic population declines (Bohn and Kershner 2002). It should be recognized that improvement may not be reflected in a two year postrestoration period and that additional monitoring may show continued, though marginal improvement.

It also should be noted that the current restoration was limited by the confined area of the stream section; however, the previous restoration efforts were able to reconnect the stream flood plain and therefore were able to provide some storage in the flood plain. This project would indicate that neither the current or previous restoration measures were enough and that further volume and flow controls are necessary for the runoff further up in the watershed, before it reaches the stream channel and the modified flood plain to achieve greater habitat restoration. Continued macroinvertebrate sampling without other watershed controls, i.e., upstream BMPs, may show marginal improvements with time, but an extensive watershed approach to control storm water of frequent discharge (smaller storms) with BMPs may yield results rather rapidly.

Stream restoration projects are becoming popular in United States and billions of dollars are being spent, but the results of water quality improvements are not known because postrestoration studies rarely occur. Restoration requires understanding of factors that caused deterioration of the ecosystem. Stream restoration alone, without addressing the entire watershed, may yield no net improvement in the health of aquatic systems.

Disclaimer: any opinions expressed in this paper are those of the writer(s) and do not, necessarily, reflect the official positions and policies of the U.S. EPA. Any mention of products or trade names does not constitute recommendation for use by the U.S. EPA. An EPA Report entitled "Evaluation of Receiving Water Improvements from Stream Restoration (Accotink Creek, Fairfax City, Va.)" was published (EPA/600/R-08/110, September 2008).

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